Discussion on the Dynamic Action of the Ocean in Building Bars.

By Lewis M. Haupt.

(Read before the American Philosophical Society, January 18, 1889.)

MR. PRESIDENT: A little more than a year has elapsed since the publication of my paper on the PHYSICAL PHENOMENA OF HARBOR ENTRANCES, and during this time it has provoked, as was expected, some discussion. It seems *à propos* that the record of this investigation should be entered in the publications of this Society, and I have, therefore, the honor of presenting for the Proceedings the following paper, entitled: DISCUSSION ON THE DYNAMIC ACTION OF THE OCEAN IN BUILDING BARS.

It is a reply to a Report of a Board of United States Engineers, before whom I had a hearing in January, 1888, relative to the methods proposed, and who rendered an adverse decision March 16, 1888, in which they ask for precedents. In presenting them it becomes necessary to take up the items of the Report *seriatim*, and reply to them specifically.

This representation seems to be the more necessary since this Society has done me the honor to endorse so highly the plans submitted in the paper before mentioned.

(1) The Report states that my paper presents—

"(1) A theory of ocean bar formation based upon the movement of the great tidal wave toward and along our coast; and (2) a theory of harbor improvement based upon the idea that this tidal action is the controlling element in the forces affecting the magnitude and position of the bars. Each of these theories will be briefly considered.

"Prof. Haupt calls attention to the natural division of the Atlantic coast into three great bays, and the effect they exert upon the relative height attained by the tide at different places along the coast. This subject is a familiar one and has no novelty. It was discussed by Prof. J. E. Hilgard in a lecture delivered before the American Institute more than seventeen years ago, in which he sets forth the only important facts connected with the tidal wave contained in the paper before us."

As this quotation creates the impression that I claim originality for these statements of facts, long well known, I must respectfully refer to the only claims which I have made specifically in the paper submitted to the Board for examination (see pages 20, 21 of pamphlet on "The Physical Phenomena of Harbor Entrances"), from which it will appear that no such claims were made. I have also referred in that paper to the United States Coast and Geodetic Survey Reports and other documents, as containing the data upon which my "theory of improvement" is based. In the reference to Prof. Hilgard's paper upon the tides, what he says is this: "Where a bay or indentation of the coast presents itself, opening favorably to the tidal wave, thus developed and decreased in width from its entrance towards its head, the tide rises higher and higher from the mouth upward. This is due to the concentration of the wave by the approach of the shores and to the gradual shoaling of the bottom."* He then proceeds to apply this general statement to the three great bays of the Atlantic coast line, by stating the observed phenomena. I do not wish to be misunderstood as claiming originality for reference to phenomena which are described in elementary teaching. My special claims concerning the dynamic action of the flood tide were limited to the local effects produced at the inlets by the flood as the controlling element, to which I will refer again. The Board do not appear to distinguish sufficiently between my statements of laws and the practical application and observations I have deduced from them.

The Report continues:

"Prof. Haupt attributes great importance to the velocities along shore arising from the tidal flow entering these bays. He, however, presents no measurements or other data from which a definite estimate can be drawn as to the intensity of the forces thus generated or comparison made as to their importance when contrasted with the numerous other forces acting upon the bars. Littoral currents, due to the tidal waves, if they exist, are masked and controlled by other forces, and especially by the well-known powerful action of wind-waves on all sandy shores. It rests with Prof. Haupt to demonstrate that his tidal currents flow along the shores of these bays with a velocity sufficient to move the material forming the bars, and this he has failed to do. The only argument in favor of this conclusion is an assertion that the general conformation of the bars along the coast accords with what his theory requires. But the facts do not bear this out."

From the above it would appear (*a*) that the engineer is expected to make a definite estimate of one of the most variable forces of nature, which may conspire with or oppose others in producing its effects; (*b*) that even the existence of littoral currents, due to tidal waves, is doubted by the Board; (*c*) if such currents do exist, it must be proven that they have "velocity sufficient to move the material forming the bars;" (*d*) that no proof has been adduced in support of the proposition enunciated, but merely assertions made to fit a theory.

In presenting the evidence in reply to this Report, I propose to show:

(1) That the *velocity* is an unimportant factor, and that material can be transported even where there is no motion of translation in the motor.

(2) That waves breaking obliquely on a sandy shore will move the particles over a zigzag path, in a constant direction. which is cumulative.

(3) That the flood tide produces such angular waves, and that littoral currents aid the movement.

* Smithsonian Report, 1874, p. 219.

(4) That the term *flood component* is more comprehensive than flood *current*, and includes the dynamic action of the breakers racing along the shore, as well as the littoral currents generated by the on-shore movement of the flood tide.

If it can be shown that the *flood currents have* sufficient energy to move materials, such as *bricks*, *coal*, *wreckage*, etc., in a *direction opposed to the winds*, even during storms, and for distances measured by miles *in the direction of the flood*, it would seem to be sufficient evidence to prove not only the *existence* of such a force, but that it is "sufficiently powerful" to move *sand* beneath the surface in the same direction.

(*a*) As to measuring this particular force, I can only reply that instruments can do little more than give an imperfect record of a special condition for a comparatively short interval of time, and that the only intelligible gauge of the combined action of the physical forces is to be found in the effects produced, as revealed by Nature herself.

A board of engineers, in reporting on Galveston harbor, expressed the hopelessness of measuring this particular force when they said :

"It will be seen that the board does not attempt any prediction of the precise depth the jetties will maintain. Such predictions can best be made by those ignorant of experience in tidal entrances elsewhere, and having great confidence in the credulity of mankind."

Yet, notwithstanding this statement, it is immediately preceded by the statement of the expectation "that the proposed jetties, when the channel is once formed, will maintain some such depth as twenty-five or thirty feet."

As yet the channel has not been formed, although dredging has been tried and abandoned, and $1,581,782.84 have been expended, chiefly on the outer bar, and the latest survey shows a reduction of depth to twelve and three-fourths feet, or less than existed, at times, before the works were begun.

In short, the measurement of this force is impracticable, since it will differ not only for different entrances, but at different points of the same entrance, and will also vary with the stages of the tide, duration and direction of wind, etc.

Speaking of the action of these natural forces, General Gillmore says : "The question is full of perplexing difficulties, which elude all the known methods of research by formulæ." 1876, p. 458, Rep. Chief of Eng'rs.

THE PROOF OF THE EXISTENCE OF THE FLOOD COMPONENTS.

(*b*) The Report says :

"*Littoral currents, due to the tidal waves, if they exist, are masked and controlled by other forces, and especially by the well-known powerful action of wind waves on all sandy shores.*" * * * "*The observed effects may be explained quite as well by the accepted wind-wave theory.*" * * * "*The* *prevailing direction of the storm winds, apparently ignored by Prof. Haupt, is an important element in the problem.*"

This wind-wave theory presupposes that the breakers and waves generated by prevailing winds and by great storms rolling along the beaches and transporting material in the direction of these movements, are the preponderating forces.

It is a plausible theory, and the effects of great storms do not admit of doubt, yet its general application in accounting for the peculiar forms of spits and bars will be found to fail signally in numerous instances, as will hereafter appear.

In replying to these points, I would respectfully submit that, as the effects of storms are immediate, and the changes readily observable, too much stress has been laid upon them, as compared with the work done by the ceaseless activity of the flood, the result of which for any one tide may be small, but it is cumulative. Thus, on the one hand, we have a great force operating for a *short interval of time* along a variable path; and on the other, a lesser force operating almost incessantly over a constant path. Assume that there are five or six great storms from the same quarter during a year, with no counter-storms to neutralize their effects. We have then an aggregate effect of some unknown quantity multiplied by 5 or 6 to be compared with some lesser unknown quantity multiplied by 730. In ten years the net result in the latter case would be tenfold greater; in a century it would be a hundredfold, and the effect would go on increasing as long as time endures. But one great storm, it must be remembered, may cut away material which the next may restore, and the resultant must always be the algebraic sum of the movements. The wind-wave theory is totally inadequate to explain the existence of the peculiar hooks and spits which have been built out directly in the face of the prevailing winds. For instance, witness the phenomena at one of the most striking and familiar formations on the coast, that of Sandy Hook. I will quote the observed facts from the Report of Profs. Bache and Mitchell, printed in 1856, U. S. C. S. Reports. Prof. Bache remarks: "It is known * * * that Sandy Hook is gradually increasing, growing to the northward into the main ship channel. A spot north of the Hook, where there was forty feet of water when Capt. Gedney made his survey, in less than ten years was nearly bare at low water. The importance of determining the cause of this increase, as leading to the means of controlling it, cannot be overestimated." * * * "Various causes have been assigned for its growth, by the action of the waves and the winds." Speaking from the results of Prof. Mitchell's surveys, he says: "It turns out that this growth of the Hook is not an accidental phenomena, but goes on regularly and according to determinable laws. The amount of increase depends upon variable causes; but the general fact is that it increases year by year, and the cause of this is a remarkable northwardly current * * * along both shores of the Hook." * * * "For more than seven hours out of the twelve, there is a northwardly current through False Hook channel." "This northwardly current runs on the inside for eleven hours out of the twelve. It is the conflict of these two northwardly currents outside and inside, and the deposit of materials which they carry to the point of the Hook, which causes its growth." * * * "Within a century it has increased a mile and a quarter."

Prof. Mitchell says: "Our attention was called not only to the more regular action of tides, currents, and the ordinary wash of the sea, but also to the effects following violent storms and other extraordinary phenomena." * * * "I will cite here the most striking case in this connection. Near the end of Sandy Hook we found many small household articles, and even human bones, which were ascertained to have drifted thither from the emigrant ship *New Era,* wrecked at Long Branch two years ago. To astertain whether the same causes were still in operation, we chose a period of quiet weather, and made deposits of sinking bodies, at points along the coast a short distance from shore. The materials pursued the same path as that taken by the wreck matter of the *New Era,* driving on to the same part of the beach after many days."

This is conclusive evidence for this place to show that it is not the *wind wave,* but the *flood current* running along shore, that has produced this spit of sand, called Sandy Hook, extending for five miles in a direction *opposed* to the prevailing winds. The observations were made with a view to determine this very point, and leave no doubt as to its correctness.

The same cause, namely, the flood current, flowing westerly along the south shore of Long Island, has built out Coney Island to the westward in the face of a strong ebb and the north-west storms.

In a Report on the improvement of the bar near Sandy Hook, a board of officers say: "Among the agencies which tend to diminish the navigable depth, are: (1) Sand moved from the adjacent shores into the lower bay. From observation, it is known that there is a gradual movement of sand in the vicinity of the low-water line northward along the New Jersey shore, and westward along the Long Island shore into New York bay. Even without special observations, the fact is sufficiently shown by the form of Sandy Hook, a sand spit about five miles long, which has been slowly built during past ages by this northward movement of sand along the New Jersey shore." * * * "An examination of the charts of Coney Island shows that its western end is moving westward as sand is moved to it, the motion of its eighteen-foot curve amounting to 800 feet between 1835 and 1881."

No cause is assigned in this Report for these movements north and west. They are merely mentioned as observed facts, but it is not to be supposed that this distinguished board of experienced officers would ascribe these movements at right angles to each other to "the prevailing direction of the storm winds," or to the "accepted wind-wave theory," since the *prevailing* direction is neither west, north, nor north-west, but is off shore, whilst the *flood-tide movement is* north-west and reacts along shore to transport the sand and drift in the direction of these extended spits. If the direction of the beach and drift movements are to be taken as indicative of that of the prevailing winds, as they should be, if the wind theory be true, then we must have the winds in the vicinity of Nantucket blowing from the S.W. ; those at New York entrance from the S.E. ; those along the Jersey coast from the N.E. ; those at Cape Henlopen from the S.E. ; those along the "Eastern Shore" from the N.E. ; those from Chesapeake Bay to Cape Hatteras from the S.E., and from Hatteras to Georgia from the N.E., with sudden reversals at Capes Fear and Lookout, and so on. In short, to fit this theory, the prevailing winds must blow from different quarters over limited sections, which the observed results, as plotted from the Hydrographic Charts, do not confirm. But, on the contrary, the *flood component* is found to approach in the direction of the shore drift and satisfactorily to explain this movement. The wind-wave theory also fails signally as applied to the Great Lakes.

The same defect of the wind-wave theory exists when applied to the Gulf of Mexico, for in a special Report* on Galveston, by a board of engineers, dated New York, January 21, 1886, occurs this statement as to the potency of the winds in producing changes on the bar :

"Twenty and one-half per cent of the winds were from the N.E. and E. ; their waves should give a south-westerly motion to the sand : thirty-six per cent were from the S. or S.W. ; these should move the sand towards the north-east."

But, as a matter of fact, the resultant sand movement is south-westerly, or in a direction *opposed* to the prevailing wind ; so that this theory is untenable in almost, if not in every instance.

The movements of the winds in the great Southern Bay may be seen from the subjoined statement of the Signal Service for this bay for the sixteen years from 1871 to 1886 :

AVERAGE FREQUENCY OF WINDS, AS INDICATED BY THE NUMBER OF OBSERVATIONS.

Direction	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calms.	Prevailing Direction.
Movement	1775	1790	1890	1724	2538	2642	1841	2061	1249	S.W.
Percentage	10.9	11.0	11.6	10.6	15.6	16.3	11.3	12.7		

STATEMENT BY YEARS.

Date	1871	1872	1873	1874	1875	1876	1877	1878
Average movement	3984	3735	4550	4739	4942	3889	5117	5034
Prevailing direction	S.W.	N.W.	S.W.	S.W.	W.	S.W.	S.W.	S.
Date	1879	1880	1881	1882	1883	1884	1885	1886
Average movement	4802	4583	5655	5179	5050	4992	5325	5334
Prevailing direction	S.	S.W.	E.	S.	S.	S.	S.	S.

From which it appears that there is not a single year in which the prevailing winds are from the N.E., but that they are generally from the S. and S.W. Hence if the forms of the spits and channels be due to these forces, they should be just the reverse of those found to exist along the

* Report Chief of Engineers, Appendix S, 1886.

northern flank of the Southern bay, where they are best defined and most characteristic.

From a more detailed analysis of these tables of monthly wind movements, quoted from the Signal Service Reports by Lieutenant Carter, U.S.E., for the vicinity of Tybee Roads, Ga , it will be observed that the prevailing winds, which are from the S. and S.W., would tend to move the sand in a direction *contrary* to its observed motion, which is towards the S.W. To illustrate the relative intensities of the opposing winds, I have collated and compared the total monthly wind movements from 1872 to 1886, inclusive. The normal on-shore winds is S.E., hence those producing a north-eastwardly movement are the S. and S.W. winds, and those producing a south-westwardly movement are the E. and N.E. winds. The remaining directions being off-shore. Assembling these in groups by years, they exhibit the following results :

						Ratio in Thousands of Miles.	*Excess.*
1872,	the S. and	S.W. winds	: to the E. and	N.E.	winds,	: : 16 : 7 =	9
1873,	"	"	"	"	"	: : 21 : 5 =	16
1874,	"	"	"	"	"	: : 25 : 10 =	15
1875,	"	"	"	"	"	: : 30 : 9 =	21
1876,	"	"	"	"	"	: : 20 : 8 =	12
1877,	"	"	"	"	"	: : 24 : 26 =	—2
1878,	"	"	"	"	"	: : 25 : 5 =	20
1879,	"	"	"	"	"	: : 23 : 14 =	9
1880,	"	"	"	"	"	: : 38 : 4 =	32
1881,	"	"	"	"	"	: : 17 : 18 =	—1
1882,	"	"	"	"	"	: : 46 : 5 =	41
1883,	"	"	"	"	"	: : 25 : 5 =	20
1884,	"	"	"	"	"	: : 27 : 10 =	17
1885,	"	"	"	"	"	: : 20 : 5 =	15
1886,	"	"	"	"	"	: : 13 : 16 =	—3
							227—6

From this comparison it would seem that the forces due to the prevailing direction of the wind, and tending to move material to the north-east, are overwhelmingly in excess of those operating in the contrary direction, or as 227,000 is to 6000 miles, an excess of 221,000 miles of wind movement from the S. and S.W. over that from the E. and N.E., or 14,733 miles per year.

It would seem, therefore, that the more deeply the wind-wave theory is examined, the more untenable it becomes, and that it is unnecessary to go further, if these tables represent the facts in the case, as I believe they do. Yet before closing this part of the argument, I beg leave to add that on the great lakes the littoral currents are found to divide at or near the *widest* part of the lakes, and to flow along shore in *opposite* directions towards the head and outlet, which could not occur were they caused by winds. How could a N.E. wind on Lake Michigan, for example, cause a current to the northward and southward from Milwaukee at the same time? These currents are due to *surface oscillations*, which are interrupted and deflected by the form of the shore line, as along the coast.

With reference to the effects of prevailing winds in moving material, Prof. Henry Mitchell, of the U. S. Coast and Geodetic Survey, says :

"The motion of the waves is not always in the direction of the prevailing winds. This fact is noted in many publications. An example of this is shown by the action of the waves on the north side of Long Island, N. Y., which drifts the material westward, while on the south side the motion of the drifted material is eastward,* and yet the prevailing winds must be essentially the same on the two sides of the island. Another example is furnished by Lake Michigan. On the west side, south of Milwaukee, the prevailing motion is southward, and north of that place it is northward, and yet the prevailing wind must be the same. The prevailing wave motion must be influenced by the tendency which wave oscillations have to move from the deep waters as a centre towards the shores. In some instances the prevailing drift, too, must be modified by the prevailing action of the littoral currents."

In short, the oscillations of the flood tide in deep water become converted into waves of translation on shelving shores, where they break at a permanent angle, and also generate littoral currents, both of which combine to move the beach material in the direction of the receding coast line.

FLOOD *vs.* EBB CURRENTS.

Again, I believe it to be an error to attribute the deep holes in the gorges of inlets to ebb action chiefly. In Ex. Doc. 78, Forty eighth Congress, in reference to the Narrows of New York bay, it is said : "The mean ordinary velocity at the Narrows is, during the ebb tide, about two feet per second, and from this a depth of 100 feet results." In view of this statement, it is strange that a greater mean ebb velocity over Five-mile Bar in the Delaware is able to maintain only about seven feet of depth. In fact, it is not so much a question of velocity as of *reaction*, resulting from the compression of the *flood* in its efforts to pass through the gorge. The surveys show that the *bottom* currents run flood for about eleven hours out of twelve, and that the resultant of all the currents, ebb and flood, is strongly up stream. It is a notorious fact that refuse, etc., dumped in the lower bay, is carried by the flood to the upper bay, and it certainly will not be claimed that this effect is produced by prevalent storm-winds or waves. The flood resultant is also lower than that of the ebb, because of its greater density. Moreover, there can be no doubt that the extension of Cape Henlopen to the northward about 800 feet and the deposit there of over 5,000,000 cubic yards in the last half century, in opposition to the strong ebb, aided by the breakwater, and of the action of the N.E. and N.W. storms, and the cutting away of the *outer* beach about 600 feet near the *point*, is additional evidence that the flood compo-

* This is only true for the eastern end of Long Island.—L. M. H.

nent exists and has the power attributed to it, which it is necessary that maritime engineers should recognize in designing successful works of improvement.

The existence of such a force as that described, and the effects produced thereby, in transporting heavy articles, and, *à fortiori*, lighter ones, is still further abundantly attested by the following record of observed facts by competent persons. The extracts in Appendix "A" are cited to establish, as the author says, a "*fundamental principle, that the deposits on the ocean border are only made by the current of the flood tide,*" and are a complete confirmation of the conclusions I have reached from an independent and somewhat different line of reasoning, based upon a comprehensive comparative study of the coast charts.

They were compiled by the late Rear-Admiral Davis,* one of the most talented hydrographers this country has produced, and were accepted by such eminent authorities as Profs. Henry, Agassiz and Guyot, but were unknown to me until my attention was drawn to them by this discussion.

(*c*) VELOCITY INSUFFICIENT?

"*It rests with Prof. Haupt to demonstrate that his tidal currents flow along the shores of these bays with a velocity sufficient to move the materials forming the bars, and this he has failed to do.*"

It would appear from this opinion of the Board that they expect the results produced by the flood to be those due wholly to the *velocity* of the littoral currents, evidently overlooking those other and far more potent agencies which are at work in the flood, as previously proved with reference to New York entrance. I have, in general, designated this force as the "*littoral component,*" but it has been confused with and mistaken for the littoral *current*, and since the velocity of the latter is evidently small, it has been concluded that there can be no motion produced by this flood *component*. I have already cited numerous unmistakable instances of such motion and deposit in opposition to the prevailing wind theory, and will now merely call attention to the fact that these results may be produced even *without any littoral current*, since matter may be given a motion of translation without the motor itself having such a motion. For example, the usual helices for mixing concrete, transport the material from one end of the trough to the other, even against gravity, merely by the rotation of the axis, and water is raised by the Archimedean screw in a similar manner. The dynamic action of the waves racing along the beach is precisely the same. If the wave of translation, as it comes rolling in, does not strike normally (and in a bay it will generally be oblique), then it will

* Chas. Henry Davis, LL.D., U. S. N., was born in Boston, Mass., January 16, 1807, and entered the navy as midshipman in 1823, becoming Rear-Admiral in 1863. In 1861, he was a member of a board to report upon the condition of the harbors and inlets of the Southern coast. In 1859 he was made Superintendent of the "Nautical Almanac;" in 1865, of the Naval Observatory, and during his active scientific and professional life, he translated the "Mécanique Céleste."

roll up the sand diagonally. The particles may possibly return normally with the under-tow, only to be again transported obliquely, and by this zigzag path it will advance in the direction of the receding beach ; a littoral current merely intensifies this action.

This movement along shore is, therefore, largely dependent on the angle at which the flood breaks upon the shore, and this angle is practically a constant for a particular place, modified by the wind. But variability in the wind is not the controlling condition. It may sometimes increase the littoral drift, and at others neutralize it entirely. While there *may* be a prevailing north-east wind, as alleged, it would seem from an examination of the hydrographic charts, that the prevailing winds are off shore and the greatest storms from the south and west. In the middle bay particularly, extending from Cape Hatteras to Nantucket, the on-shore winds are limited to a few months during the summer. It would appear from these charts that the prevailing winds, and consequently the wind waves, can have very little influence in transporting material along the shores at or below the water line.

With reference to the existence of a constant angle for the breaking wave as well as of a littoral current, Prof. Henry Mitchell, of the U. S. Coast and Geodetic Survey, says : "From considerable experience in the study of waves upon the open coast, I have come to the conclusion that there is everywhere a *prevalent*, if not a *permanent*, angle at which the larger class of swell or rollers strike the general shore line ;" also, "the coast currents in some places have a velocity of one-third of a mile per hour in thirty fathoms of water. They are in some localities nearly parallel, in others normal to the general trend of the shore line, and, so far as the few observations we have seen may indicate, the directions of ebb and flood are not usually opposed, although lying at an oblique angle with each other."

Dr. Whewell says, concerning the action of the flood tide : "The cotidal lines make a very acute angle with the shore line, and run for great distances nearly parallel to it. They are convex in the direction of their motion, the ends near the shore being held back by the smaller velocities in shallower water and other resistances."

But there can be no holding back without a reaction upon the shores, whereby the sandy particles would be dragged by the friction in the direction of this movement.

Mr. E. A. Geiseler, C.E., formerly Assistant U. S. Engineer and Superintendent of Construction on Light-house Service, says : "I fully coincide with Prof. Haupt in his opinions that littoral currents are produced by the entrance of the tidal wave into bays. From the higher crest the water *must* flow at first vertically to such crest towards the shore line, and on approaching the latter be gradually deflected into a direction parallel to it."

From the reference of the "tidal currents," to me personally, as their discoverer or imaginer (see quotation), it is necessary here incidentally to disclaim any originality for the discovery of their existence. What I did claim and emphasize in my paper was not that, but their efficiency and controlling influence as bar-building agencies, and I applied the knowledge of the direction of the flood component to the designing of a plan for successfully resisting these encroachments. Although hydrographers are familiar with the well-known increased height of tide in bays, and with the existence of the littoral currents, they appear to have failed to apply these phenomena to account for the transportation of drift, until they were found, by a specially conducted series of surveys and observations, to be the causes of such formations as are instanced in the case of Sandy Hook. Yet, notwithstanding ample evidence, there are many persons who still adhere to the wind-wave theory as exerting the most potent influence.

(*d*) "*That no proof has been adduced, but merely assertions to fit a theory.*"

After the instances already given, it would seem to be superfluous to cite as evidence any more facts. The theory was not conceived first and then generalizations added to fit it, but it is the logical outcome of a critical study of the forms, slopes and positions of the topographical features at a large number of entrances, taken in connection with the general form of the coast line, and the conclusions I have reached are merely confirmatory of those deduced at earlier dates by Profs. Bache, Mitchell, Hilgard, Rear-Admiral Davis, some of the members of the United States Corps of Engineers, many civil engineers, and by some light keepers, life-saving crews and wreckers. I think it is clearly demonstrated that there is a flood component of greater or lesser intensity, depending on the angle at which the flood movement breaks upon the shore, and that it is the cumulative effect of this force that builds and moulds the bars at harbor inlets, or wherever there is a break in the beach. Such an opinion accords with observed facts, explains them satisfactorily, and is accepted by the most experienced hydrographers and maritime engineers.

The Report of the Board continues :

"For example, we have authentic records at one of the sites he (Prof. Haupt) quotes, Beaufort, N. C., which prove that during the last sixty-seven years there has been a cycle of changes, and that the channel over the bar which, at present, occupies the position required by his theory, would have borne testimony adverse to its truth a few years ago. Indeed, such changes are a common occurrence along the coast. The accepted opinion of engineers who have had large experience in harbor works on sandy coasts, is that the action of oblique wind waves is potent in causing the movement of material along the shore, and that the prevailing direction of the storm winds, apparently ignored by Prof. Haupt, is an important element in the problem."

The above statement concerning the cyclic changes which are found to exist at the inlets, is but another confirmation of the correctness of the theory. These changes occur *in the same direction* through a cycle of years, and are due to the relation between the flood and ebb forces. The flood resultant, by its constant encroachments from *the same direction*, trespasses upon the path of the ebb, crowding it over towards shore, and filling its bed, until it is no longer able to find an escape in the old path, when, aided perhaps by a storm, it will break out in a new channel, only to be returned after a series of years over the same ground. If these changes were due to storms only, they would be far more variable, and, in the interval between storms, they would be comparatively permanent. The channel would be thrown to the south-west by a north-east storm, and to the north east by one from the opposite quarter, when equally exposed, and there they should remain until again disturbed by this violent action ; whereas such is not the rule.

The changes at Beaufort and all other places are readily explained by the influence of this unceasing flood resultant, modified only temporarily by storms.

The reason why the *storm-wind* theory is the accepted one, is doubtless due to the fact that the effects are, for the time being, more manifest to the superficial observer, whilst those of the flood component are imperceptible excepting after the lapse of considerable time. The effect may be likened to the slow growth of an organic body, not visible to one watching it constantly, but very apparent to one who makes examinations at long intervals. The storm winds, it will be seen, are not ignored by me, but are merely relegated to their true position of secondary agencies, which may co-operate with or oppose the forces of the flood tide.

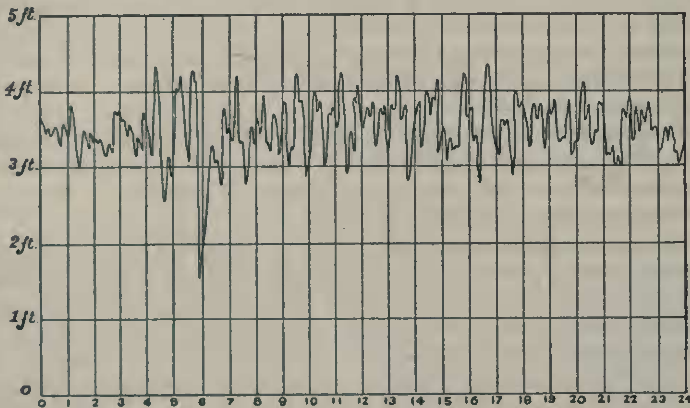
In consequence of this cyclic movement it is evident that it would be a mistake to assume that *all* the ebb channels should remain flexed in a certain direction along one flank of a bay and in the contrary direction on the opposite flank, as some have supposed must result, or that the changes would occur simultaneously at all places.

The Board continue :

"Nothing which Prof Haupt has advanced suggests that his tidal current should be substituted as the 'controlling' or even as an important element in our ocean bar formation. The observed effects may be explained quite as well by the accepted wind-wave theory. Indeed, the fact that such bars abound on shores where no sensible tidal waves exist, proves that no new theory need be invoked."

The first part of this statement has already been answered, and if the last part were irrefutable the theory would be untenable. But since like causes must produce like effects, if the observed effects are found on tideless shores, we must expect to find the same causes—and so we shall. Whether the motor be universal or terrestrial gravitation, the agency is primarily a wave of oscillation which in shallow water becomes a wave of translation, breaking generally obliquely upon the shore and producing a resultant movement along the beach. It is a well-known fact that on the

Great Lakes which, in the passage quoted, are undoubtedly the waters alluded to by the Board, there are continual oscillations of even greater magnitude than are found to be produced by the tides in the Gulf of Mexico, and that they are much more frequent, hence the effects more marked. In the observations made by Rudolph Hering, Consulting Engineer for the Chicago Drainage Commission, he shows for one day not less than seventeen oscillations of over a foot in amplitude, and one of them exceeding two and one-half feet. (See diagram.)



Fluctuations of the water surface of Lake Michigan, as recorded by an Automatic Gauge, Chicago, Ill., August 16, 1886.

NOTE.—The wind was from the north-west in the morning and the south-west in the afternoon. The lake here is sixty miles wide and from twenty-five to fifty fathoms deep.

Mr. Hering says : "The winds and barometric pressure produce a constant oscillation of the surface, and at times a swinging motion from shore to shore. * * * One oscillation on the above diagram is distinctly recognizable as lasting about twenty minutes, which is the swing across the lake. The greatest of these, as will be seen, was over two feet. The oscillations are relatively greatest at the south end of the lake."

Concerning these observed oscillations of the lake's surface, Mr. O. B. Wheeler, an experienced Assistant on the Lake Surveys since 1862, who was continuously employed upon these surveys for thirteen years, and subsequently at intervals to date (1888), writes as follows :

NOTES ON THE WATER-GAUGE RECORDS OF THE GREAT LAKES. BY O. B. WHEELER, M. AM. SOC., C.E.

"From my remembrance of the discussion of the self-registering tide-gauge observations made at several points and for several years on the Great Lakes, I offer the following :

"In these gauges the ordinary wind waves and waves from passing vessels, or from any local, incidental causes, were eliminated by means of the perforated boxes surrounding the float.

"A fair representation of the record is shown in the illustration by Rudolph Hering in his paper to the Engineers' Club of Philadelphia; although there is a distinctive curve for each locality of observation, and the curve for Chicago would be distinguishable from that of Milwaukee or from that of any other locality.

"The curve at Milwaukee showed that for more than half the season of observation there were series of waves coming in at intervals of approximately two hours, whose height were from one-third of a foot to one and a half feet. Generally the waves are subdivided, sometimes very deeply, into two or more parts. At Milwaukee, on Lake Michigan, there were more nearly eleven of these waves in twenty-four hours, and at Marquette, on Lake Superior, eight in the same length of time. The two-hour interval at Milwaukee was supposed to be due to the time required for a wave to travel across the lake and return, where the width of the lake was nearly eighty miles and depth 400 feet.

"Greater disturbances, known as 'seiches,' occurring generally several times in a season and lasting several hours, bring waves upon the shore at intervals of twenty or thirty minutes, the crests of which waves exceed two feet in height above the troughs. The cause of this phenomenon is probably a difference in atmospheric pressure on different parts of the lake, and the more decided 'seiches' probably result from severe cyclones. The same cause may for the most part account for the generation of the two-hour waves above noted.

"There is also a change in the relative water level of the two ends of a lake due to the direction of the wind, but the wave thus produced has generally a day or more in length of duration."

Mr. G. Y. Wisner, a colleague of Mr. Wheeler's, also an experienced Lake Survey Assistant, writes, under date of March, 1888, that "the laws of the natural forces, which you have so ably set forth in your article, as applied to tidal harbors, hold equally true with a large number of the harbors on our lake coasts. It is true the tides on the lakes are imperceptible, yet other natural causes combine to produce the same effect."

"Owing to unequal barometric pressures on different portions of such vast bodies of water, series of waves are generated which are usually about an hour in passing from crest to crest at any given point, and vary all the way from six to eighteen inches in amplitude. These waves follow each other along the shores similarly to those of flood tides; their effect in generating littoral currents depending, of course, on the general direction in which the waves approach the shore and the conformation of the coast line. I have noticed the rise and fall of the lakes due to this wave action, for days at a time, in perfectly calm weather, with almost the regularity of clock-work, and have observed currents generated in the open lake of over three miles per hour. * * * Most of the lake harbors are the mouths of rivers, and exhibit in a very striking manner many of the characteristics which you have described."

Mr. Wisner has subsequently prepared a paper on this subject for the use of the profession, which paper is published in the "Proceedings of the Engineers' Club of Philadelphia" (1888), giving the practical applications of these phenomena to several of the lake ports.

The application of the observed principles to the lakes becomes very simple. As a lake contracts at its head (as at the west end of Lake Superior, the south end of Lake Michigan, the west ends of Erie and Ontario) it may be regarded as a large bay with converging shores. The oscillations in midlake are reflected along these shores and broken into waves of translation rolling towards the bight. Here, if there is any land drainage entering the lake, there is an opposition between the drifts in these directions, and a precipitation of materials usually from both shores ensues, forming long spits, as at Minnesota and Wisconsin Points, on Superior bay, and at Chequegomegon spit on the bay of the same name. Similar formation takes place from the same causes at Maumee bay, at the head of Lake Erie, and at the end of Lake Ontario. Like movements in Lake Huron drive the sands into the St. Clair river and thence into the enlargement known as Lake St. Clair, which was so shallow before improvement, as to have been the controlling feature on the lower lake navigation.

The same action at the head of Lake Michigan has, I believe, closed the ancient southern outlet, via the Kankakee river, to the Illinois and Mississippi, and is still at work closing the mouths of the streams at that and other points and creating extensive deposits of sands. The same effects are to be found generally at the indentations of the shore line of sandy formations.

Prof. Hiero B. Herr writes from Chicago, under date of March 30, 1888, that "our sand-propelling currents are southward on the south half of the shore and northward on the north half. This seems clearly proven by the rapid accumulation of sand deposit on the north side of projecting piers in the former case, and on the south side in the latter."

From these numerous instances, therefore, it is believed to be a fact that this shore component of the lake oscillation and "seiches," be they produced as they may, by wind or barometric disturbance, is the principal agency in producing the characteristic forms found there, as on the alluvial coast line.

This brings us to the second branch of the Report of the Board, in which they comment upon my practical deductions.

The Board say:

"The practical deductions drawn by Prof. Haupt from his theory are illustrated by proposed plans of improvement at the harbors of New York, Charleston and Galveston. They are all similar in character, consisting of a single detached jetty made up of elliptical curves presenting their cusps to oppose the supposed advancing component of the tidal wave, and of an in-shore extension to concentrate the flood current upon a secondary or 'beach' channel, which it is proposed to keep open. At New York and Galveston 'detached breakwaters' are indicated, to prevent the ebb from being diverted from its course, and to train it upon a point where, according to his theoretical deductions, 'the bar-building forces are weakest.'

"Without going into any general discussion of this typical plan, it will be sufficient to point out: (1) That since no provision is made to close the 'beach' channel during ebb tide, it will carry off water which might be more usefully applied to scouring out the main or 'ebb' channel, and that one good channel is certainly better than two bad ones; (2) that this proposed main channel, in the case of Charleston, is so lengthened by its location, that the working energy, due to the difference of head between the harbor and the outer ocean, is frittered away by being distributed over a path needlessly long; and (3) that the degree of contraction on the bar is ill-defined, uncertain and altogether insufficient."

To any one at all familiar with the original plans of the Government engineers for both Galveston and Charleston, the above criticism of my methods must appear as singularly inconsistent. If there are serious objections in the plans which I have submitted, they must apply with much greater force to those now being executed at so great expense to the Government.

The whole merit of the submerged jetty plan, as adopted, was based upon the theory that the flood would be admitted freely over the jetties at their shore ends, and be, at ebb, trailed by them out across the bar, where the jetties were to be raised to or above the surface of the water. If the loss of ebb energy through the comparatively small lateral opening left in my plans be of serious amount, it would be far more so when the lateral openings amount to nearly four hundred per cent of the section at the mouth of the jetties, as is at present the case at Charleston.

As to my proposed channel being so lengthened as to fritter away the working energy due to difference of head, it is only necessary to say that the point of escape for the ebb at all these sites is, in my plans, nearer the gorge, giving a greater slope and more rapid discharge than in the plans now under construction. At Charleston, the most unfavorable case for me, it is but two and seven-eighths miles distant from the gorge, while the mouth of the Government jetties is about three and one-eighth miles distant.

"ONE GOOD CHANNEL *versus* TWO BAD ONES."

There is no doubt that one good channel is to be preferred to two bad ones, but the counter-proposition that "two bad ones" are better than no good one is likewise true, and when it is remembered that the forces relied upon to create and maintain the *two* channels are distinct, are operating at different times and places, there would seem to be no reason why they may not both be created. A fairer statement of the case would be that two good channels would be better than *one* poor one. *Apropos* of the amount of water escaping laterally during the ebb through the beach opening in the breakwater, the Reports of the Chief of Engineers are explicit in stating that it would be much less than the amount admitted during flood; and in view of the beneficial effects of the 600 feet gap in the great north wall of the Dublin entrance,* there would seem to be no room left for doubt as to the benefits to be conferred by such a vent as that which I have proposed. The loss of energy through this lateral outlet during ebb would be immaterial; as it lies close under the lee of the shore, and nearly the whole of the ebb is trailed to discharge over the bar at the curved outer end of the breakwater.

In discussing the Government projects, it was originally deemed fundamental to their success that the flood tide should be admitted freely to secure the necessary prism for ebb scour, and in the design for the beach channel entrance, which I have given, I have provided a form that must pass *more* flood than ebb, and hence the excess would go to increase the ebb at another point of the bar. It is this *difference* of quantity upon which I rely in part to increase the efficiency of the ebb as well as the conservation of its energy over nearly one-half the crest of the bar. These principles are universally accepted as sound. They certainly will not fritter away the energy available for scour in an "ill-defined, uncertain, or altogether insufficient action," but must concentrate all there is to be had over the most limited as well as the weakest section of the bar.

In considering the utility of high jetties for Charleston, the late General Gillmore said: "The excess of ebb over flood scour is due to two causes: (1) To the rainfall of the natural drainage area; (2) To the volume of water carried in over the bar by waves of translation, which afterward form a part of the general outflow. High jetties, or those which rise above the level of high water, will cut off all supply from this source, except what little is carried in between them." * * * And he adds: "There are few maritime constructions, says M. Minard, less susceptible of general rules and more dependent on local influences than jetties. He might have added that we are as yet unable to deal with these local influences with much confidence or satisfaction." To avoid these defects of high jetties the Government has tried the submerged plan with, thus far, no better success.

CONCLUSION OF THE BOARD.

"In fine, the Board, after an attentive study of Prof. Haupt's paper, supplemented by a personal interview, in which he was afforded every opportunity to explain and elaborate his views, find that they are purely theoretical, are unconfirmed by experience, and contain nothing not

* See Franklin Institute Journal, for April, 1888.

already well known, which has a useful application in the improvement of our harbors.

"A copy of the printed paper submitted to the Board by Prof. Haupt is herewith enclosed. Respectfully submitted.

(Signed by) "Thos. Lincoln Casey, Colonel Corps of Engineers.
"Henry L. Abbot, Col. of Engineers, Bvt. Brig. Genl.
"C. B. Comstock, Lt. Col. of Engrs., Bvt. Brig. Genl.
"D. C. Houston, Lt. Col. of Engrs., Bvt. Col.
"W. R. King, Major of Engineers."

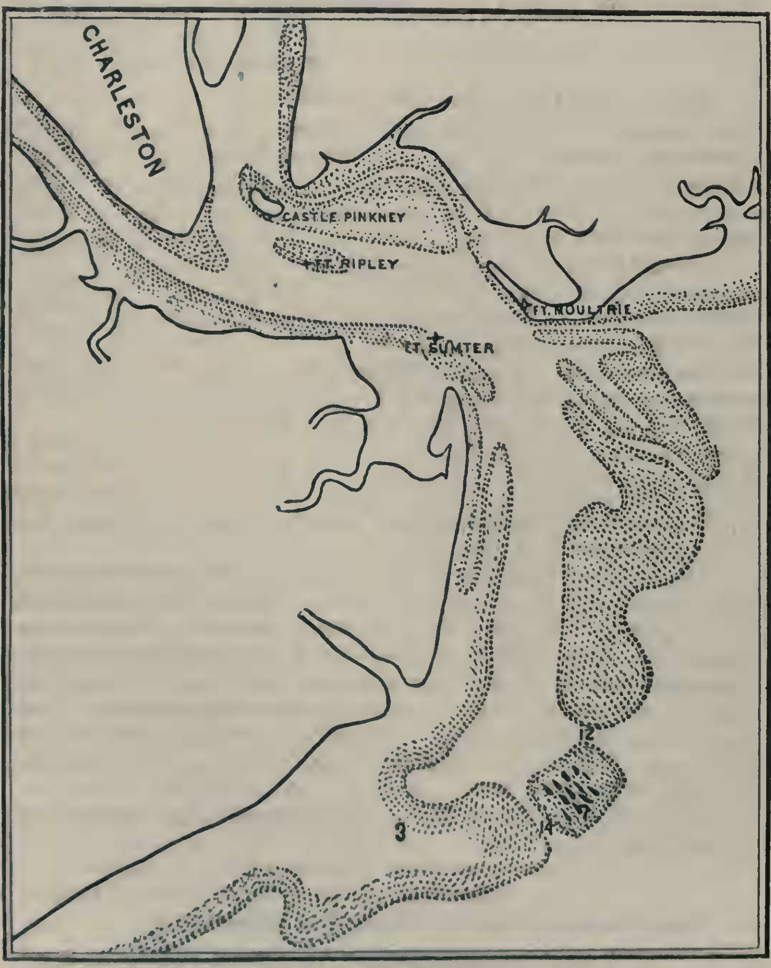
From the above concluding remarks it will be seen that the Board find in the paper submitted "nothing not already well known, etc.," and that the plans "are purely theoretical and unconfirmed by experience." These conclusions appear to me to be contradictory, since if, on the one hand, they are new and untried, they could hardly be expected to be confirmed by experience, or if, on the other hand, they are "well known," they are, by that expression, impliedly recognized as true, and their application should be readily confirmed or denied by the supposed existing precedents. But none have been cited by the Board.

In the paper of Prof. Hilgard, to which the Board allude in their Report, he describes the, to him, *unexpected* effects produced during the war by the sinking, on the Charleston bar, of the so-called "stone fleet," thus obstructing the entrance to the harbor.

Prof. Hilgard says:

"On the accompanying diagram is seen the 'stone fleet' sunk in the main channel, which at that time had twelve feet of water at low tide, where the figure seven indicates the present depth. There was, moreover, another channel, making out more to the southward, with nine feet of water, where the figure three indicates the present depth. The vessels were placed checkerwise, in such a manner as to impede navigation, while interfering least with the discharge of water. The effect, nevertheless was the formation of a shoal in a short time, and the scouring out of two channels, one on each side of the obstructions, through which twelve and fourteen feet can now (January 27, 1871) be carried at low water. The increased waterway thus given to the ebb tide caused it to abandon the old nine-foot channel on the less direct course to deep water. We have here the total obstruction of a channel, which was of considerable importance to the southward trade, by new conditions introduced at a point four miles distant from where the effect was produced, and we are warned how carefully all the conditions of the hydraulic system of a harbor must be investigated before undertaking to make any change in its natural conditions, lest totally unlooked-for results be produced at points not taken into consideration."

So that instead of obstructing the entrance this accidental barrier to the flood actually deepened the water on the bar two feet, and induced the ebb currents to effect an escape in its lee, closing a channel several miles to the westward by furnishing a line of less resistance, and withdrawing the water from the former distant channel. Moreover, it cut a second channel quite as deep as the first on the opposite side of the fleet, thus creating TWO *channels as good or better than before,* instead of the one formerly existing on the site of the fleet.



There could not be found an instance more fully confirmatory of the soundness of the principles I have laid down and proposed to use, than this accidental practical experience, and yet the amount of the protection afforded by the "stone fleet" was much less than that I have provided, and it is situated at a point where its effects might have been considered "altogether insufficient, uncertain and ill-defined."

(The cut is reproduced from Prof. Hilgard's paper, Smithsonian Report, 1874, page 221.)

The accompanying letter, recently received from Prof. Hilgard, is conclusive as to the probable efficiency of these plans :

"1349 L St.
"WASHINGTON, May 20, 1888.

"MY DEAR PROF. HAUPT : I have received your interesting paper on the 'Physical Phenomena of Harbor Entrances,' in which you describe the peculiar forms of the bars and spits found at the inlets along the sandy cordon of islands defending the Atlantic coast line and give your explanation as to the forces producing them ; ascribing them chiefly to the energy of the flood tide as affected by the general form of the coast line.

"In this I think you are entirely correct, as it is undoubtedly the unceasing activity of the flood that produces the forms which are so characteristic of harbor entrances, and not the wind waves produced by prevailing winds. The direction of motion of the beach sands is, as a rule, the same as that of the flood tide along the shore. It is modified by great storms, but only temporarily, and in a short time the flood reasserts its supremacy and the channel returns to its normal position.

"In applying this physical fact to the plans for improving the bars, I believe you have proposed the best form to resist the encroachments of the sand and yet admit the flood tide freely. These are fundamental conditions, and you have fully met them while providing at the same time ample facilities for navigation.

"The successful operation of your proposed plan is well illustrated by the accidental experience with the stone fleet on Charleston bar, described in my paper on 'Tides and Tidal Action in Harbors,' published in the Smithsonian Report for 1874. From that instance it is seen that by obstructing the inflow of sand and inducing an ebb current, two good channels were formed, the better one to the leeward of the obstruction. Your plans would change the conditions of equilibrium in favor of the ebb, and the length of your breakwater is much less than that required by existing methods.

"I trust that they will be tried at some suitable entrance along the Atlantic or Gulf coast.

"Yours, with great regard,

"J. E. HILGARD.

"PROF. LEWIS M. HAUPT, University of Pennsylvania."

The effects to be anticipated from the shore flank of the breakwater are best instanced by those found at the Delaware breakwater, where a straight barrier of half a mile in length stands at such an angle to Cape Henlopen as to have been originally tangent to it when projected in 1828. Its end is about a half mile from shore, and it is open to the north-west storms and ebb scour. It has maintained a channel 600 feet wide and over thirty feet deep through the shoals, which have been built upon either hand, all the way to the deep water of the Atlantic, and notwithstanding this concentration of the ebb forces through this funnel-shaped passage, the flood was not prevented from rolling Cape Henlopen about 800 feet farther north since the commencement of the construction of the breakwater. These detached instances, with that of the Dublin harbor north wall, are all conclusive, so far as any precedents can be, as to the effects to be expected from my plans, and when it is remembered that the cost of executing them would be less than half that of the high and tight jetties now proposed, and that the effects of time will be to reinforce and strengthen rather than to destroy them, it would seem that, in justice to the commercial interests of the country, an opportunity should be found for at least giving them a fair trial.

In further confirmation of the requirement that the jetty should be on the side toward the flood component, reference is made to the experience of a private company, at Aransas pass, on the Texas coast, in 1869, which is believed to be the only case of this kind on record.

Here the movement of sand is *southward* at the rate of over 200 feet per annum, and this company expended less than $10,000 in building a short jetty only 600 feet long from the *north* shore and extending out on the *north* side of the channel.

"These jetties, crates or caisons, as they are variously called by the builders, were made of live-oak poles, spiked together in the general form of a triangular prism and placed longitudinally. Each crate was about eight or ten feet long, six feet high and six feet wide at the base. * * * They were ballasted with a few hundred-weight of stone, filled with brush and sunk in two or three parallel rows. They were expected to act as a nucleus about which the sand would settle, and close up the secondary channel, thus directing the flow of water directly through the channel of the bar. From the fact that the secondary channel has shoaled about two feet, and the main channel deepened about two feet since placing the crates, it may be supposed they have contributed to produce this result."*

In a later Report, dated February 1, 1879, Maj. Howell, then in charge, in commenting upon this early precedent, remarks:

"From my remembrance of a verbal description of the work * * * the cribs were triangular in cross-section (dimensions not known), and their parts very imperfectly fastened together, and besides seem to have been made of any timber and lumber that came handy—some live oak, but mostly yellow pine scantling, four inches by six inches.

"Some of these cribs were filled with brush and stone when sunk in place, but it is said that others were simply ballasted so as to sink them.

* Report of the late Lieut. E. A. Woodruff, Corps of Engineers, dated April 1, 1871, *vide* Report Chief of Engineers, 1871, p. 526.

During the work of construction some of the cribs near the shore were broken up and washed away.

"When the work was suspended it is said there was a twelve foot channel across the bar, which was maintained for several months, possibly until the teredo and the waves had destroyed a considerable part of the frail cribwork.

"In 1871, when the late Lieut. E. A. Woodruff made a reconnoissance of the pass, he was unable to find any trace of the work. It is said that as the work gradually disappeared the channel across the bar gradually returned to its normal depth. I consider my information reliable as to the above described work and its effects."

These extracts show very conclusively that, so far as this frail structure went, it was in the proper place, and did effective work in improving the channel by keeping out the sand and preventing the dispersion of the ebb. Its form and materials might have been improved to great advantage.

The Government failed to profit by this precedent, however, for in August, 1887, the engineer officer in charge of this pass, reported that:

"The work designed to deepen the channel over the bar, consisting of a single jetty, constructed upon the south side of the entrance, has had no important effect upon the bar, and is in a dilapidated condition. The channel depth, over the bar, is now eight and one-half feet, and the channel crosses the jetty."

Thus it appears that this jetty was attempted on the wrong side (the south) of the channel, and that the ebb discharge in seeking the line of least resistance was forced over the crest of the submerged work by the bar of sand rolled up by the flood component.

JETTIES IN PAIRS.

This paper would be incomplete without the evidence collected by experienced maritime engineers of other countries, as to the results of similar works elsewhere.

In his digest of jettied entrances, Sir Vernon Harcourt says in general of the jetty system:

"The jetties also, in most cases, were extended in the hope of reaching deep water, which proved fruitless, owing to the progression of the foreshore with each extension of the jetties. Next artificial sluicing basins were formed, to provide a larger mass of water for sluicing, with the additional advantage that the issuing current was nearer and better directed for scouring the entrance. Lastly, dredging with sand-pumps is being largely employed for deepening the channel beyond the jetties. The parallel system has not proved successful in providing a deep entrance without constant works. * * * Experience has shown how jealously encroachments on the tide-covered lands should be prevented, and the uselessness of prolongations of the jetties. * * * Parallel jetty harbors are one of the most difficult class of harbors to design and maintain successfully."

Again, the President of the Institution of Civil Engineers of Ireland, and Engineer of the Port of Dublin, J. Pursur Griffith, writes with reference to the alluvial harbor at Ostende, Belgium :

"It is not necessary to enter into a detailed description of the successive additions made to the jetties and sluicing reservoirs * * * suffice it to say, that the jetties extend at present about 300 metres seaward from the shore line, and the maximum sluicing capacity of the reservoir is about 1,100,000 cubic metres. The result of these costly works cannot be regarded as satisfactory. The channel is still shallow, while the bar a short distance beyond the pierheads still forms a dangerous obstruction. *Depth of water at the entrance to a port is more needful during rough, wild weather than in calm, and it is just at such times that sluicing operations similar to those at Ostende fail.*"

Speaking of the jetty system in general, he says :

"The system so generally adopted in Continental ports, of parallel or nearly parallel jetties, extending only to comparatively shallow depths, appears to be radically wrong in principle. Their tendency, generally, is to act as groins, and make the sandy shore extend outwards until the sand passes around the pierheads where the action of the sea heaps it up in the form of a bar."

It seems unnecessary further to multiply instances of the failure of the principle of parallel jetties in tidal waters, and it is confidently believed that the single-curved barrier placed upon the bar as an obstruction to flood-wave and sand movement will be found satisfactorily to fulfill the requirements of these problems.

APPENDIX A.

Extracts from a paper, by Charles Henry Davis, Lieut, U. S. N., entitled "The Law of Deposit of the Flood : Its Dynamical Action and Office." Printed in the Smithsonian Contributions to Knowledge, Vol. iii. Referred to a Commission consisting of Prof. S. Agassiz, Prof. A. Guyot and Prof. Joseph Henry, and accepted December, 1851.

"The views in the paper* were founded upon observations and examinations of various parts of the alluvial coast of the United States, through a series of years, and led to the discovery that the shape, extent and distribution of the loose material of which they are composed—quartzose sand—were chiefly determined by the action of tides." * * * "It

* The author here refers to a previous memoir on the same topic.

was laid down as a fundamental principle, that the deposits on the ocean border are only made by the current of the *flood tide*. * * *

"The mode of operation of the flood is essentially accumulative. Its tendency, also, is continually to carry onward the deposit in the course of its current, so that it performs the double office of increasing the collection at every successive tide, and of advancing from place to place the matter at its disposal. This process, and the law by which it was produced, were proved by the manner in which the materials of wrecks were conveyed along the shore, and the direction (always that of flood) in which the various forms of deposits are increased. Many well-authenticated instances of the transportation of wrecked matter were adduced." He adds, "It is difficult, if not impossible, to make these inquiries through another person with a perfectly intelligible result, * * . * it has not, therefore, been possible to add many facts to those already collected. The following statements are well attested."

Mr. J. H. Skillman, Inspector of the Port at Greenport, L. I., stated that in October, 1842, the whale-ship *Plato* was wrecked on the south side of Long Island, and he took part in the purchase of the wreck. "After removing the oil, the upper frame separated from the lower timbers and drifted to the westward. The wreck masters built a house on the beach, in which they lived two weeks, employed in rescuing the cargo and materials of the vessel. During this time bricks (spare ones for the 'try-works') and wood drifted to the westward, and were collected on the beach in that direction only. Nothing was carried to the eastward. The top frame that had separated was heavy, water-logged, and weighed down with iron fastenings, it floated deep; and at the time of its drifting to the westward, the wind was blowing from the west. The bricks and fire-wood constantly advanced in a westerly direction. During three of the fourteen days passed by the wreckers on the beach, the wind was from the north-west and one day very strong; at no time did it blow from the east. After the hull was lightened it began to work to the westward, so that it was necessary to secure it by ropes, made fast to stakes driven into the sand."

Mr. Bishop, speaking of the British sloop-of-war *Sylph*, lost on the south side of Long Island in 1814–15, said that: "The materials of this wreck were also taken up to the westward, some of them beyond Fire Island beach during the three weeks following her destruction. And, curious to relate, her rudder was found seven years afterwards, twenty miles to the westward of the place of her loss. It was known by its size and the king's arrow on the copper." Other cases are cited, and the statement is made that the flood current on that part of the Long Island shore runs to the westward.

Lieut. Com'd'g J. N. Maffitt, U. S. Coast Survey, says: "Cape Hatteras is a point of divergence of the tide wave, or, in other words, a split of the tides takes place there; in consequence of which the advancing flood that supplies the harbor of Charleston flows along the coast from the north to the south." He adds that, "the water, while it runs *flood*, is loaded with sand; but that, when it runs ebb, it contains little or none of this matter."

The action of the flood is to roll a floating body forward and lift it up, carrying it in the direction of the flood and finally leaving it stranded at high water.

"Again, if a strong wind should arise to cause a heavy sea upon the beach, the floating body will be thrown still farther on the shore." * * * "If, during the ebb tide, a floating object be placed upon the water, outside of the line at which the sea breaks, it will be taken off, but if inside the breakers, it will be cast upon the shore. From these facts it appears that there is a mechanical action, by means of which the water, when in contact with the shore, ejects the substances either floating upon its surface or held by it in suspension, and that the effect of the flood current is to transport these substances and place them within the reach of this action, and that of the ebb is to transport these substances beyond the reach of this action. That is to say, what is called the law of deposit of the flood tide may be divided into two distinct phenomena; one of which is the transporting power of the flood current towards and on to the shore; the other, the dynamical action of the water at the shore."

"So, then, the inward tendency of the wave action on the shore ejects or rejects the matters brought under its influence, and the transporting power of the flood current bears them from place to place, bringing them finally under this influence. And further, the projected particle will not strike the beach perpendicularly to its length, but obliquely, so that it will advance, as it rises on the shore; and in this manner, also, the combined action of the two forces leads to the accumulation of deposits in the direction of the flood tide."

In the Memoirs, American Academy of Arts and Sciences (New Series, Vol. iv), pages 138, *et seq.*, the same author cites a number of instances of wrecks along the south shore of Nantucket, and remarks: "In none of the instances were any of the wrecked materials seen to the westward of the spot where they first struck the island; that is, in the direction of the ebb. This is well known to be universally the case, so that wreckers never go to the westward, but always to the eastward in searching for floating articles. The fact is the more striking, that this course is opposed to the violent north-east gales, the principal cause of loss to shipping. For the preceding details I am indebted to Mr. Mitchell, of Nantucket, the astronomer," and others. "But the characteristic action of the flood may be observed with even greater distinctness on the eastern shore of Cape Cod. There is a separation or split of the tides * * * and the tide currents, at this place, appear to run on and off shore. Now, the materials of vessels that are wrecked to the southward of the seat of division of the tides are uniformly carried south, and are found inside of Chatham harbor or of Monomoy Point; while vessels that are wrecked so far north as to be within reach of the northern current of the flood have their effects scattered along the north shore, and making occasionally the entire circuit of Cape Cod, are soon deposited in Provincetown harbor. Here also, as at Nantucket, the movement is opposite to the prevailing winds. The transportation of such heavy materials as coal and bricks has been mentioned."

Mr. Small, the keeper of the light at Truro, said that "When articles float light upon the water, and offer a large body to the resistance of the wind, they may during the violence of the storm be carried against the current. During seven-eighths of the time, the waves break on the shore at Truro in a direction to the northward of west, the shore itself running north and south. This takes place in *opposition* to northerly winds. If these winds are exceedingly strong, they may for a short time overcome this prevailing tendency. It is the same on the eastern shore of Sandy Hook and of Nantucket. As the flood tide runs in a northerly direction at each of these places, the idea is suggested that there is an intimate connection between the course of the current and the manner of approach of the waves to the beach." * * * "The constructive process of the flood is equally exhibited in the way in which the hooks, etc., are built up. They extend and increase always in the direction of the advancing current, as, for example, the Great Point of Nantucket gains constantly to the north, and the point of Monomoy to the south, which are the directions of the flood currents at these places. * * * And so with all the hooks, both great and small, of the north-eastern coast, whether formed on the borders of the sea or in enclosed bays and harbors."

Hitherto the *tides* have been regarded chiefly as an astronomical problem; but if the views brought forward in this memoir are correct, they must hereafter be treated also as a strict geological problem. It has been shown that the courses of the tidal currents must in general be due to the forms of the shores" (page 148). "In this memoir, the forms, localities and amounts of the alluvial deposits have been attributed to the active influence of local currents."

Notes on the Botocúdus and their Ornaments.

By Prof. John C. Branner.

(*Read before the American Philosophical Society, November 16, 1888.*)

The Botocúdus of Brazil have been described at more or less length by Prince Maximilien,* Auguste de St. Hilaire,† Lery,‡ Denis,§ Bigg-

* Voyage au Bresil, par S. A. S. Maximilien (French translation from the original German), Vol. ii, p. 207 et seq.

† Voyage dans les provinces de Rio de Janeiro et de Minas Geraes, par Auguste de St. Hilaire, 2 vols.

‡ Histoire d'vn voyage faict en la terre dv Bresil, par Jean de Lery, p. 103–4.

§ Bresil, par Ferdinand Denis. This work reproduces five plates of these Indians.